

## The Pie Town Wideband Fiber Optic Link Project

R.J.Beresford Email : Ron.Beresford@atnf.csiro.au  
CSIRO Australia Telescope National Facility PO Box 76 Epping NSW ,1710 ,AUS  
National Radio Astronomy Observatory ,PO Box 0 Socorro NM ,87801 ,USA

*Engineers and scientists at the NRAO have successfully demonstrated the longest real-time wide-band fiber optic link so far used in radio astronomy. The 104km fiber route ,part of the Western New Mexico Telephone Co connects the National Science foundation facilities :the Very Large Array (VLA) ,and an antenna of the Very Long Baseline Array (VLBA) system at Pie Town (PT) ,NM. PT is located 52kms west of the center of the VLA. Early imaging work with the PT antenna linked to the the VLA confirmed double the VLA resolution with the sensitivity of the VLA*

The PT link provides the interface between the VLBA antenna and the VLA for all seven common receiving bands , P band (327MHz) through to Q band (45GHz). The VLA correlator has inputs for 27 antennas only. Conceptually it was decided to switch out a “donor” VLA antenna and switch in the PT antenna to the correlator. This scheme also permitted reuse of existing hardware and software modules. Considerable challenges were expected in the transmission of a phase stable ,high dynamic range composite 200MHz analog passband from PT to the VLA.

A system overview can be found in Figure 1.

The PT antenna converts the PT sky frequency to the nominal 500-1000MHz Intermediate Frequency (IF) range for both Right Hand Circular (RCP) and Left Hand Circular (LCP ) polarization's. The IF's are amplified and split two ways. These IF's are then converted to the nominal VLA 50MHz wide channels centered at the usual Frequency Division Multiplexed (FDM) VLA waveguide frequencies. Channel A 1325MHz RCP , channel B 1425MHz LCP Channel C 1575MHz RCP ,Channel D 1675MHz LCP.

Four separate Local Oscillators (LO) driving triple balanced mixers provide the conversions. The LO's have programmable low side VHF( 339.9 - 689.9MHz) or high side UHF (2260.1 – 2610.1MHz) outputs. The use of VHF or UHF is determined by the Single Sideband (SSB) sense required to maintain compatibility between the quite different antenna conversion architecture of the VLA and PT. In order to allow any antenna of the 27 VLA / PT combination to be the geometric center of the array ,fringe rotation has been added to the PT LO's.

Hydrogen MASER frequency standards at each site provide the basis for RF phase synchronization between sites.

The fiber link comprises state of the commercial art in the deployment of current telecommunication components and techniques for the low loss (0.2dB/km) 1550nm International Telecommunications Union (ITU) window. A loss of 23dB was measured for the 104km length of “dark” fiber provided by the telephone company. Cornerstone to the implementation of the PT link was the capacity to have several optical carriers coexist on a single fiber core.

Optical Wavelength Division Multiplexing (WDM) is used to transmit mixed signal, wide-band, bi-directional optical signals over standard (high dispersion 18ps/nm/km) single-mode fiber core.

The use of WDM was influenced primarily by the cost of fiber rental and the use of new innovative optical methods applicable to future construction projects.

The optical system design is based on Direct Detection Intensity Modulation (DDIM).

At the PT VLBA antenna A,B,C,D IF channels are each separately Automatic Level Controlled (ALC) and combined together with a 1200MHz tone derived directly from the PT maser. This combined signal then externally modulates the RF fiber optic link.

The unidirectional RF fiber link uses a high power 50mw Distributed Feedback Laser (DFB) at  $\lambda_1=1554\text{nm}$  externally modulated by a Mach-Zehnder (MZ) modulator to an optical modulation depth (OMI) of approximately 1%. Using cascaded Thin Film Dichroic Interference filters (DIF) for the WDM function,  $\lambda_1$  is extracted at the VLA end then envelope detected in a PIN diode photodetector. A received optical power of  $-17\text{dBm}$  is present. Due to the large optical loss  $\sim 26\text{dB}$  including DIF filters, this part of the system is essentially thermally noise limited. Using purpose built MATHCAD simulations a theoretical Spurious Free Dynamic Range (SFDR) of  $85\text{ dB Hz}^{(2/3)}$  was predicted.

Two-tone test methods revealed a SFDR of 26dB in 200MHz bandwidth. Small differences in derived and measured SFDR can be attributed the PIN diode  $50\Omega$  impedance mismatch. The RF link operates with a nominal SNR of 20dB, with 6dB dynamic headroom. Due to the suboctave nature of the design 2<sup>nd</sup> order intermodulation was found to be of less concern.

Although for the most part radio astronomy signals are band limited white noise signals, ever increasing interference from terrestrial and satellite communications dictates higher dynamic headroom preventing generation of third order intercept products. With the same interference at both the VLA and PT it can potentially cross correlate more effectively than the desired radio astronomy signal.

Particular care in the design of a thermally stable laser control. A tolerance of  $\pm 0.01\text{C}$  was required at  $\lambda_1$  to ensure the multiplicity of dispersion and laser operating wavelength did not produce unwanted phase variations.

Dispersion compensation was deemed inappropriate due to the high loss (6dB) of dispersion compensating fiber required.

Topologies with Erbium Doped Fiber optical Amplifiers (EDFA) were considered to boost the SFDR. Placement of a EDFA at a position approximately half way along the fiber was thought logistically unsound given practicalities of maintenance and accessibility to telephone company infrastructure.

Two further wavelengths are used to WDM lower power 10mW directly modulated on/off keyed DFB optical signals at  $\lambda_2=1530\text{nm}$  and  $\lambda_3=1535\text{nm}$  from opposing ends of the fiber providing a bi-directional 800Mbit/sec digital communications path for monitor and control of the PT link and equipment racks between sites.

A Hewlett Packard "G-Link" Time Division Multiplex TDM chipset provides a 16 wire virtual parallel bus between the sites. Signals important to the interferometry such as the noise diode "on" synchronization and the VLA waveguide event synchronization are sent in this

manner. Although an unused feature, provision has been made to multiplex via the chipset a “B” channel tie line enabling direct CISCO router interconnects.

The four IF's A,B,C,D are converted in the VLA “donor” antenna backend electronics rack at the VLA site. In typical VLA fashion the IF's are converted to base-band and 2bit quadrature sampled. The digital bit streams representing the analog are delayed up to 675 $\mu$ S in the 108 modified delay cards prior to correlation utilizing larger First in First Out Memory FIFO. This large delay is required to account for both the radio delay over 52km between PT and the VLA and the 500 $\mu$ S transmission line delay arising from 104km of fiber refractive index  $n=1.4$ .

The 1200MHz tone sent from PT to the VLA provides convenient one-way phase reckoning between the two MASER frequency standards. Further work is proceeding in this area to dissociate the transmission line induced phase artifacts from the MASER drift non-linearity.

In addition there were other non-linear effects generic to long length of glass requiring substantial design effort.

Stimulated Brillouin Scatter SBS, a non-linear effect with narrow line width high power optical carriers and long fibers, in practice reduces the maximum launch power to less than 4mW without appropriate optical spectrum spreading.

The Optical Return Loss ORL approaches a finite value of 32dB with the long line Rayleigh Backscatter accumulation (RBS). This is particularly hampering to the construction of a true round trip (bi-directional) phase transfer LO scheme as the SNR is limited by the ORL at the transmission RF frequency.

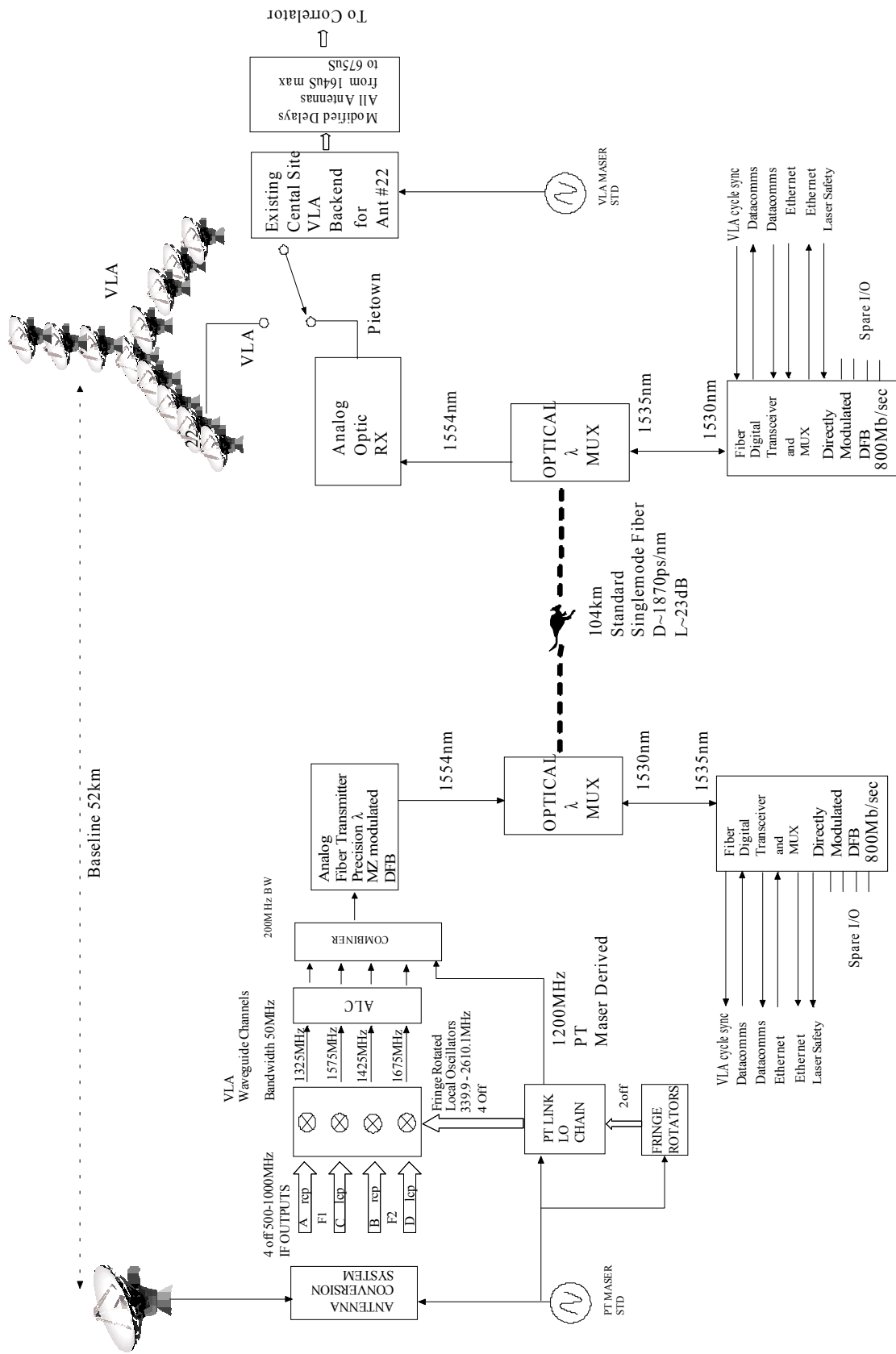
The effects of Polarization Mode Dispersion PMD can contribute to 3 degrees of slow moving random phase aberration at the IF frequencies used.

The Four Wave mixing process prevalent in WDM designs was analyzed using the Virtual Photonics Design Suite PTDS CAD. Potential Four Wave interference products were calculated to be at least 50dB down but were never found during practical spectral analysis.

First images performed with a 30 minute observation of galaxy 3C84 at 4.8GHz (6cm) on 12<sup>th</sup> Aug 99 are indicative of high dynamic range images. Figure 2 depicts VLA image only while Figure 3 depicts VLA with PT baselines included, clearly illustrating double the resolution of Figure 2.

Ensuing tests have been performed up to 45GHz with useable visibilities.

The PT-VLA feature will be available to users for scheduled radio observations during the October 2000 A-array configuration.



**VLA**

**PIETOWN**

Figure 1 VLA/PT Block Diagram

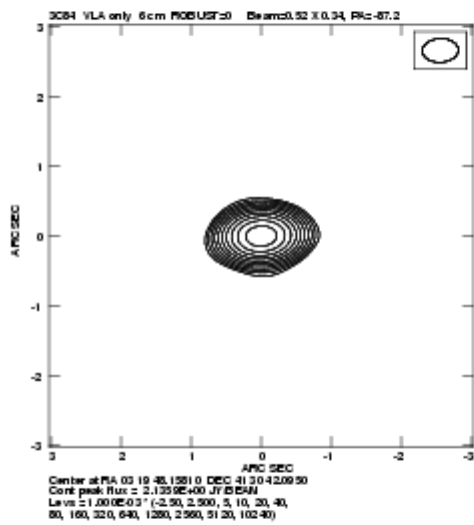


Figure 2 VLA only

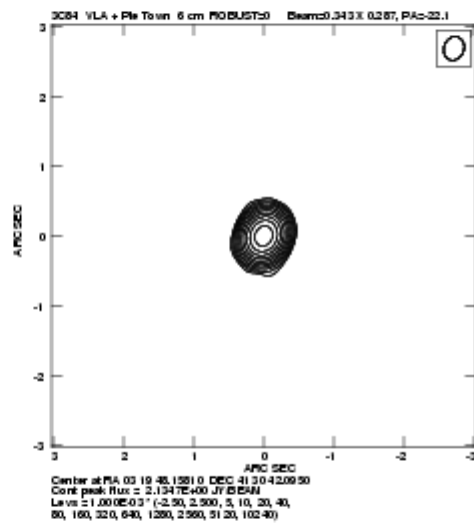


Figure 3 VLA with PT

